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Small Airframe Manufacturer's Icing Perspective

Airframe Icing Workshop
NASA Glenn Research Center
June 9th, 2009

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Agenda

- Background/Perspective
- Icing Effects & Mitigation
- Icing Certification
- New Technologies
- Summary and Recommendations

Background/Perspective

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Product Line

- **Cessna currently offer ten models with FIKI* approval**
  - **Two models offer equipment for inadvertent icing**

***FIKI** = Certification for **F**light **I**nto **K**nown **I**cing

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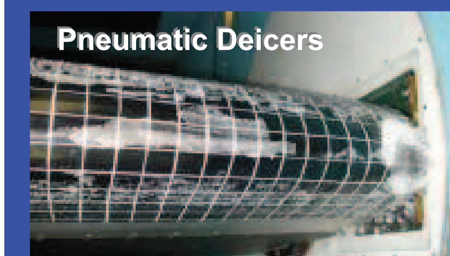
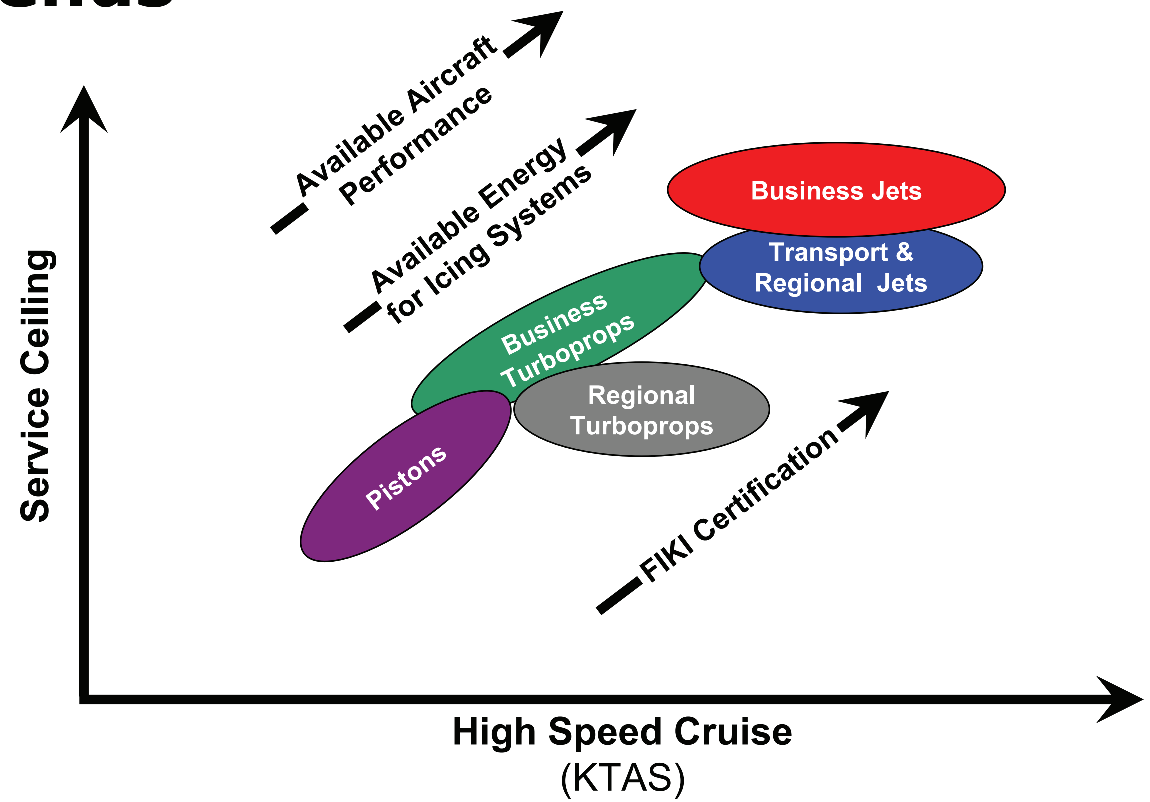
Aircraft Size/Technology

Aircraft	MTOW	Certified Ceiling	Max Cruise Speed	Wing	Stabilizer
Citation X	36,100 lbs	51000 ft	525 KTAS	Red	Red
Citation Sovereign	30,000 lbs	47000 ft	458 KTAS	Red	Red
Citation XLS+	20,200 lbs	45000 ft	441 KTAS	Red	Blue
Citation CJ4	16,950 lbs		435 KTAS	Red	Blue
Citation CJ3	13,870 lbs		417 KTAS	Red	Blue
Citation CJ2+	12,500 lbs		418 KTAS	Red	Blue
Citation CJ1+	10,700 lbs	41000 ft	389 KTAS	Red	Blue
Citation Mustang	8,645 lbs		340 KTAS	Blue	Blue
Grand Caravan	8,750 lbs	25000 ft	184 KTAS	Yellow	Yellow
Caravan 675	8,000 lbs		186 KTAS	Yellow	Yellow
400 Corvalis TT	3,600 lbs		235 KTAS	Yellow	Yellow
350 Corvalis	3,400 lbs	18000 ft	191 KTAS	Yellow	Yellow



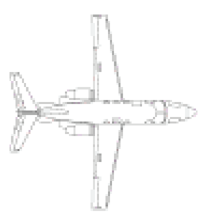
Trends



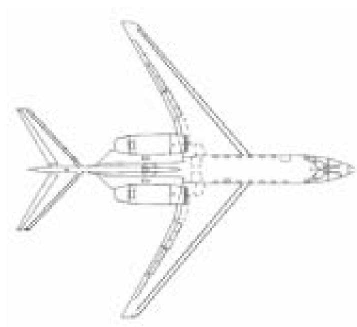
FIKI = Certification for **F**light **I**nto **K**nown **I**cing

Characteristics of Small Aircraft

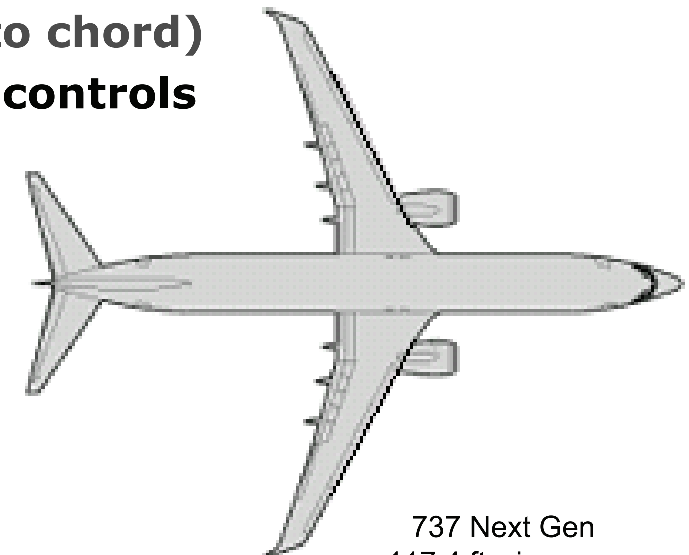
- **Small leading edges have high water collection rates**
  - **Increases local water catch rates**
  - **Increases relative size of ice shapes (w/ respect to chord)**
- **Typically unpowered flight controls**
- **Majority are fixed leading edges**



Citation Mustang
43.2 ft wingspan



Citation X
63.9 ft wingspan



737 Next Gen
117.4 ft wingspan

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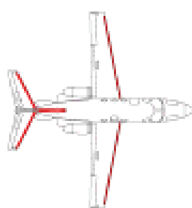
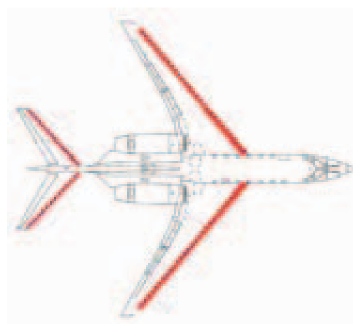
Protected Areas

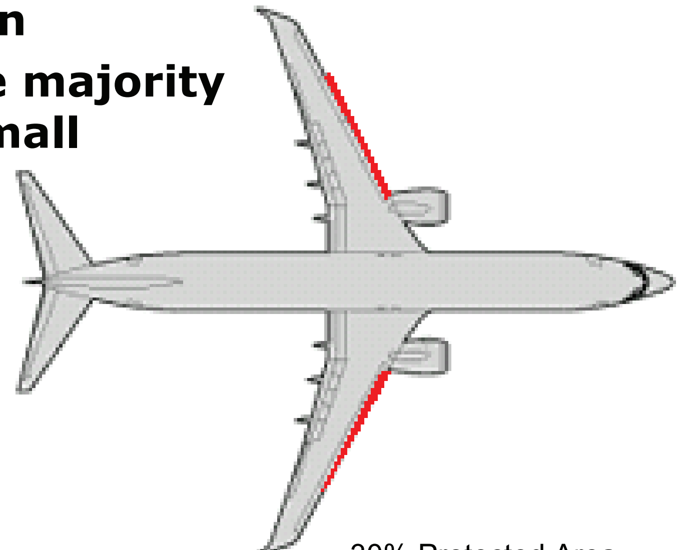
- Small aircraft typically protect a much larger percentage of the airframe
- Large proportion of available energy is required for ice protection
- Protected areas provide the majority of aerodynamic effect on small aircraft



~90% Protected Area



~88% Protected Area



~30% Protected Area

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Icing Effects/Mitigation

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Icing Effects on Small Aircraft

- Scale effects limit the ability of small aircraft to operate unrestricted in icing
- Performance effects can be significant
- Current ice protection technology can not protect against "severe" icing
- Severe conditions require
  - Avoidance
  - Monitoring
  - Identification and exit

FAA Aeronautical Information Manual: **Severe -** The rate of accumulation is such that deicing/anti-icing equipment fails to reduce or control the hazard. Immediate flight diversion is necessary.

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Risk Mitigation

DESIGN

- Aerodynamic Configuration
- Airframe Ice Protection Systems
- Engine Ice Protection Systems
- Air Data Sensors
- Stall Warning/Protection
- System Safety Aspects

CERTIFICATION

- Validation of aircraft performance & handling qualities (w/ ice shapes)
- Validation of ice protection system performance
- Validation of Operating procedures and Limitations
- Validation of Abnormal & Emergency procedures

OPERATION

- Training
- Preflight planning/exit strategies
- Adherence to operating limitations and procedures
- Avoidance and exit from severe icing

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Icing Certification

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Current Icing Certification

- **Icing certification has taken an increasing role in mitigating icing risk**
  - Small aircraft standards amended in 1993
  - Large aircraft standards amended in 2007
  - FAA Guidance/Policy continues to evolve
- **As part of certification, extensive flight testing is performed with artificial ice shapes**
  - Natural icing is typically a validation of the results of the artificial ice shape testing
- **Artificial ice shapes provide the data used to develop performance information, operating procedures and limitations**

NASA's Connection to Certification

- Most small aircraft manufacturers rely heavily on NASA developed simulation tools
- LEWICE 2D/3D are the primary ice accretion codes in use for certification
  - Primarily used for unprotected ice shapes
- LEWICE is also used to provide collection efficiencies and impingement limits that are used in designing protection systems
  - Water catch distributions are also used as input to heat and mass transfer analysis
- NASA IRT is often used for developing protected area ice shapes for certification

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Conservative versus Accurate

- **Conservative ice shapes are required for certification**
  - With respect to aerodynamic effect
- **However, excess conservatism can have unintended consequences**
  - Too high of stall speeds adversely affects approach speeds/landing distances
  - Excessive drag can affect performance and climb information
- **As such, conservative and accurate ice shapes are an objective**

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Certification Changes

- Certification ice shapes are transitioning from a single operating point to scenario based shapes
  - Takeoff ice, Final takeoff ice, En route ice, Holding ice, Approach ice, Landing ice, "sandpaper" ice
- Large droplet rulemaking define scenarios for recognition and exit of conditions
  - Requires transitions between Appendix C and Appendix X icing conditions
- Current available version of LEWICE does not address such scenarios

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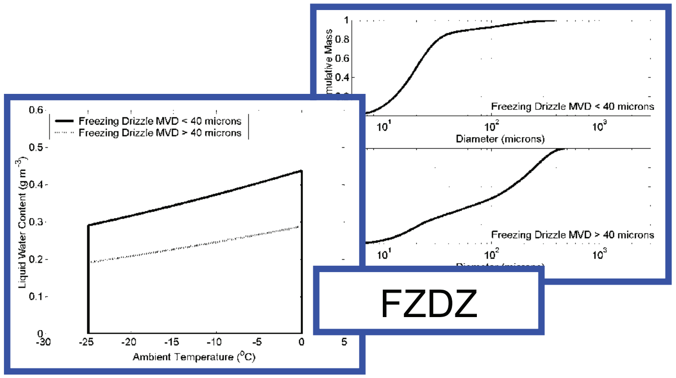
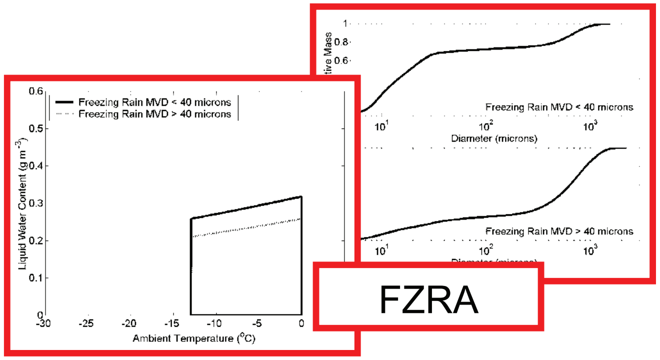
Future Icing Certification

- **Draft rulemaking has been proposed for SLD**
- **Options include:**
  - **Unrestricted operations**
  - **Unrestricted in a portion**
  - **Detect and exit**
- **Simulation and compliance methods are limited**
- **Interim methods focus on detect & exit**





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IPHWG

Phase IV Review

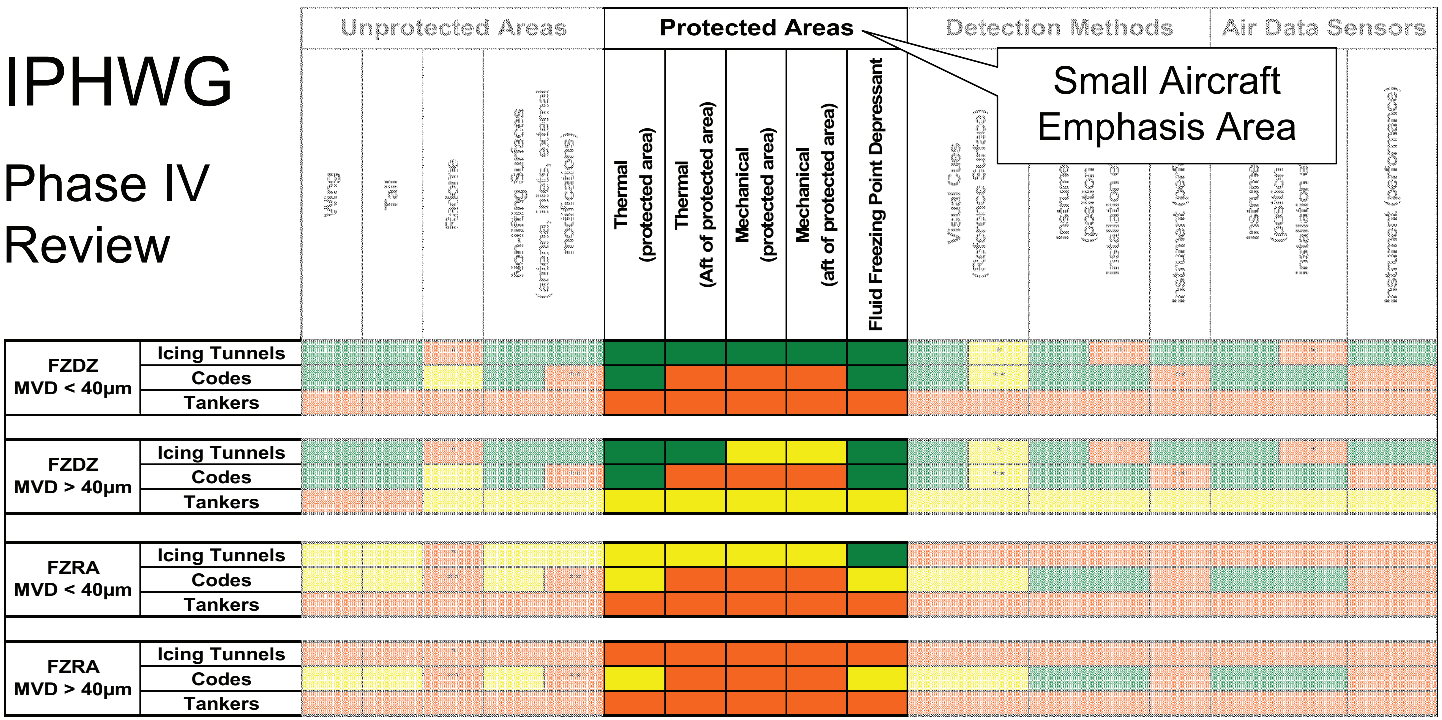
		Unprotected Areas: Wing	Unprotected Areas: Tail	Unprotected Areas: Radome	Unprotected Areas: Non-lifting Surfaces (antenna, inlets, external modifications)	Protected Areas: Thermal (protected area)	Protected Areas: Thermal (Aft of protected area)	Protected Areas: Mechanical (protected area)	Protected Areas: Mechanical (aft of protected area)	Protected Areas: Fluid Freezing Point Depressant	Detection Methods: Visual Cues (Reference Surface)	Detection Methods: Instrument (position or installation effects)	Detection Methods: Instrument (performance)	Air Data Sensors: Instrument (position or installation effects)	Air Data Sensors: Instrument (performance)
FZDZ MVD < 40µm	Icing Tunnels	Green	Green	Orange *	Green	Green	Green	Green	Green	Green	Green / Yellow *	Green / Orange *	Green	Green / Orange *	Green
	Codes	Green	Green	Yellow	Green / Orange **	Green	Orange	Orange	Orange	Green	Green / Yellow **	Green	Orange **	Green	Orange
	Tankers	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange
FZDZ MVD > 40µm	Icing Tunnels	Green	Green	Orange *	Green	Green	Green	Yellow	Yellow	Green	Green / Yellow *	Green / Orange *	Green	Green / Orange *	Green
	Codes	Green	Green	Yellow	Green / Orange **	Green	Orange	Orange	Orange	Green	Green / Yellow **	Green	Orange **	Green	Orange
	Tankers	Orange	Orange	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
FZRA MVD < 40µm	Icing Tunnels	Yellow	Yellow	Orange *	Yellow	Yellow	Yellow	Yellow	Yellow	Green	Orange	Orange	Orange	Orange	Orange
	Codes	Yellow	Yellow	Orange **	Yellow / Orange **	Yellow	Orange	Orange	Orange	Yellow	Yellow	Green	Orange	Green	Orange
	Tankers	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange
FZRA MVD > 40µm	Icing Tunnels	Orange	Orange	Orange *	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange
	Codes	Yellow	Yellow	Orange **	Yellow / Orange **	Yellow	Orange	Orange	Orange	Yellow	Yellow	Green	Orange	Green	Orange
	Tankers	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange	Orange

LEGEND Updated FEB 2009

- Green: The capability exists today and is suitable to be an element of a means of compliance, or is readily achievable based on current experience
- Yellow: The capability is possible, but has not been demonstrated, or there is limited or no validation.
- Orange: The capability is unknown, or does not currently exist
- * It may be possible to test small scale installation effects, but large scale installations are not currently feasible
- ** Current 2D capabilities exist with large droplet effects, but limitations exist in the use of 3D codes for simulation of Appendix X effects

IPHWG

Phase IV Review



LEGEND	Updated FEB 2009
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Simulation Efforts

- As illustrated, much work remains to mature SLD simulation methods
- With individual icing tunnel tests on the order of $500k to $1M, no individual manufacturer has the resources to mature simulation methods
- This effort is best accomplished through joint efforts between NASA and industry
  - Benefits flying public by improving safety
  - Conserves limited resources

Balance of Needs

- Much of the funding for icing research appears to have shifted towards engine/ice crystal research
  - This area is less mature than SLD and requires significant research and development
- However, the maturity of the SLD simulation methods will likely have a larger near term impact on icing safety
- Continued development of both the ice crystal and SLD technical areas is recommended

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New Technologies

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New Technologies

- **Continued interest in new technology ice protection systems that balance design parameters**
  - Energy requirements
  - Aerodynamic effects
  - Weight
  - Reliability
  - Affordability
- **Severe icing detection methods**
  - For both Appendix C and SLD

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Summary and Recommendations

Summary

- **NASA's simulation tools are essential for aircraft development and certification**
- **Artificial ice shapes developed using these tools are fundamental to the certification process**
- **Continued maturation of SLD simulation tools are essential for future certifications**
  - **Particularly combined effects of SLD with ice protection systems**
    - → **Potential accretions aft of protected areas**

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Needs/Recommendations

- **Atmospheric research that supports a detect and avoid strategy**
- **Aircraft level simulation of icing effects**
  - Current certification standards provide a rigorous evaluation prior to field operations
  - Provides the basis for any aircraft specific training that may be required
- **Computational simulation of ice accretions during scenarios**
  - Changing icing and aircraft conditions, etc.
  - Aligns LEWICE with current regulatory requirements

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Needs/Recommendations (cont.)

- **Performance of ice shapes with well defined separation features is fairly consistent with scale**
  - Can be readily simulated in scale wind tunnel tests
- **Roughness based ice shapes still present challenges with respect to scale**
  - Reynolds number issues
- **Ability to effectively model roughness based ice shapes is critical for design and certification**
  - Improved predictability of full wing stall behavior
  - Ties in with aircraft level simulation of icing effects

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Recommendations: NASA's Role

- **Provide technical leadership**
  - Roadmaps, consortiums, industry cooperative programs
- **Fundamental research to be used in simulation methods**
- **Continued support of development and certification tools (with focus on SLD)**
  - Proactive approach to icing safety
  - Addresses the issue before the aircraft are placed in the field

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Questions?